ADVANCED LIGHT SOURCE STRATEGIC PLAN

March 2005

With the approaching full realization of Director Chemla's original strategic plan, the ALS stands at a pivotal point in its history. The available straight sections are built out or spoken for, and only a few of the super bend lines remain uncommitted. The emphasis of the new strategic plan outlined below is to keep the ALS at the cutting edge for the next 2–3 decades by the honing of our existing stock and by the creation of sharper tools that exploit the very significant advances in accelerator and insertion-device technology that have occurred since the ALS began operation. The plan dovetails neatly with the scientific priorities of the DOE Office of Basic Energy Sciences. It is also responsive to the needs of our users, not only in the provision of scientific tools, but also in the provision of a safe and congenial research environment

Berkeley Lab

T A B L E   O F   C O N T E N T S

1. Strategic Philosophy

An early version of the plan was offered as part of the Office of Science Twenty-Year Facilities Roadmap. We proposed an orderly upgrade at modest cost having three components: upgrade of the source, upgrade of the older insertion devices, and new application-specific beamlines. The plan has subsequently been fleshed out in a series of workshops and meetings with our user community (see Appendix) and with input from our Scientific Advisory Committee.

The ALS is a world-class facility optimized for advanced spectroscopies. As it enters a new phase of maturation, the ALS is in a position to address many fundamental questions, such as: Where are the electrons? Where are the atoms? Where are the spins? Our focus throughout the strategic planning process has been on the qualitatively new science that would be enabled by the upgrade of the source. The number of ALS users will shortly exceed 2,000 per year, which requires us to devote increased attention to nurturing our vibrant user community. We will also concentrate on initiatives that will continue to make it possible for ALS users to address grand scientific and technological challenges with incisive world-class tools. The rank ordering of the projects in some sections below reflects this current sense of priorities. Several of the challenging areas that can be addressed at the ALS are

- Size-dependent and dimensional-confinement phenomena at the nanoscale.
- Correlation and complexity in physical, biological, and environmental systems.
- Temporal evolution, assembly, dynamics and ultrafast phenomena.

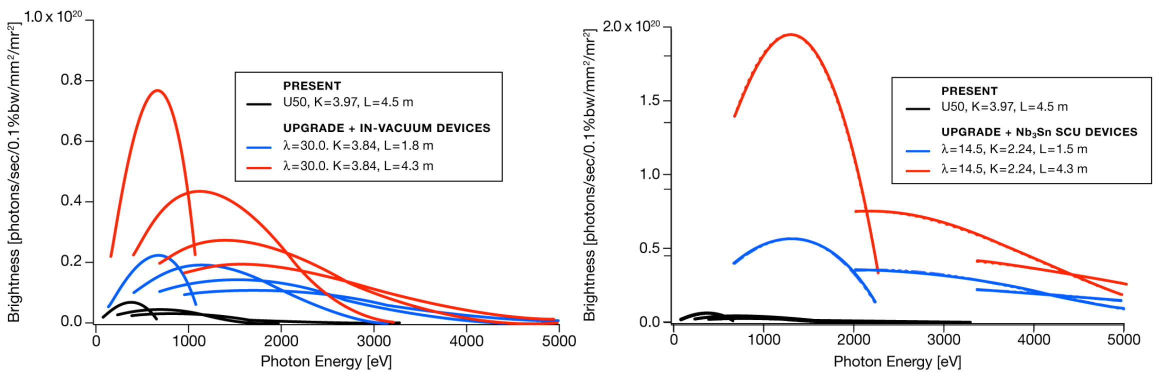
The planning process is ongoing, with further workshops and reviews in the coming months to validate the scientific need, to organize the teams, and to create detailed designs for each major component of the plan. We recognize that the priorities could change. For example, if the MERLIN project turns out to be as successful as we believe, the follow-up QERLIN project could move up in priority. Likewise, if picosecond crabbing turns out to be truly viable, then beamlines based on this process could move up dramatically from their current ranking.

2. Accelerator Upgrades and Additions

2.1. Top-Off Operation

Our highest priority is to establish top-off operation of the storage ring, with 500 mA current. Top-off was pioneered at the APS, with excellent results. Much as in the case of the APS, we expect to benefit from increased time-averaged current (in our case, a 100% increase), and much-improved stability of the beam due to a constant heat load on the accelerator vacuum chamber and, especially, on beamline optics.

Implementing top-off will reap even higher benefits at the ALS than at the APS since, at our lower-energy ring, lifetimes are shorter because of the Touschek effect. To keep the lifetime reasonable in our normal operations, the ALS is running at a considerably lower brightness than its full capability. With top-off, this compromise will no longer be necessary, and the emittance of the beam will decrease fivefold, thus providing an increase in brightness. The improvement in the absolute stability of the beam with top-off becomes even more important for the resulting smaller source size. In addition, we plan to operate with small-gap in-vacuum undulators, further enhancing the brightness, especially in the important energy range above 500 eV.



ALS brightness curves

Concurrent development of NbSn$_3$-based superconducting undulators will extend the reach of ALS undulators, especially in the multi-keV range. The combination of top-off and these new insertion devices will allow us to increase the brightness from 8 to over 100 times, depending on the specific undulators and photon energy in use.

Top-off requires upgrading the booster from 1.5 GeV to 1.9 GeV operation, significant changes to the radiation-protection system, and a variety of other hardware and control improvements. The detailed design was completed and validated by an external review committee in November 2004. The total cost will be $4.85 million. With support from BES, we are starting to procure the long-lead-time components, and we will upgrade to a full-energy injector in a mid-2006 shutdown. After the shutdown, we will slowly migrate to top-off injection, with higher currents and smaller emittance.

2.2. Picosecond Crabbing

In the machine area, our second priority is for further study of a picosecond bend-magnet source. Based on the concept put forward by Zholents, our accelerator group and AFRD's Center for Beam Physics found that by inserting crab cavities in two adjacent straight sections, vertical beam height can be traded for pulse length on the bend-magnet beamline located halfway between them. This will then be an exceedingly powerful source of, roughly, 1-ps pulses, creating opportunities for high-repetition rate, ultrafast timing experiments.

3. Optics, Detectors, Beamline Upgrades

Currently there are 35 beamlines operating at the ALS, including 8 beamlines dedicated to macromolecular crystallography. These form the core resource for the increasing scientific impact and productivity of the facility. While some of the older beamlines will be retired as new, more powerful beamlines come on line, the rest need to be maintained or further improved to reach the state-of-the-art level.
For example, to take full advantage of the increased brightness made possible by top-off operation, it is important to upgrade the beamline optics to match the source capabilities. We plan to have an orderly program to replace mirrors and gratings on highly productive older beamlines so as to bring them up to current standards. This is a highly cost-effective way to keep the facility at the cutting edge.

3.1. Detectors

Available detectors are not well-matched to the capabilities of the ALS and other high-brightness synchrotron radiation sources. There is need for a broad-based program to benefit the community, based in part on high-energy-physics detector developments, to create high-rate pixel detectors. In addition, high-speed streak cameras are needed to fully utilize the femtosecond sources coming online. The ALS, in cooperation with the LBNL Engineering Division, has started work in these areas. Because of its importance to our user program, we plan to expand detector development and bring it to successful conclusion via technology transfer to a commercial supplier.

3.2. Optics

Many of the experimental stations at the ALS depend on high resolution focusing devices – zone plates and mirrors – for world-class performance. Many of these were developed at the Center for X-ray Optics (CXRO). The continued development and availability of these optics is essential to the future success of the facility.

4. Beamlines Under Construction

Currently there are five beamlines under construction, three based on undulator sources, one based on a regular bend magnet, and one on a superbend. Completing these in a timely manner has very high priority.

4.1. PEEM-3 (Beamline 11.0.1)

Exciting questions, such as the pinning mechanisms in magnetic domains, can only be answered with extremely-high-resolution instruments. PEEM-3 is the next step in the development of advanced imaging capabilities at the ALS. It will be installed at an undulator beamline designed specifically as a source for an aberration-corrected photoemission electron microscope (PEEM-3). The beam line and undulator (elliptically polarizing type—EPU) are funded by DOE BES at a total cost of $3.7 million. PEEM-3, currently being designed at the ALS, is planned to have a spatial resolution down to a few nanometers. The system will be primarily used for studying magnetic and polymer nanostructures.

4.2. Ultrafast X-Ray Facility (Beamlines 6.0.1 and 6.0.2)

Studying atomic motion at the molecular-vibration timescale requires new tools. Designed to increase the availability of femtosecond x rays at the ALS a thousand-fold, this undulator beamline will be used for x-ray diffraction and spectroscopy with 200-fs time resolution. Ultrafast studies can give rise to a new *Science of Excited States*. One can witness the birth of an elementary excitation. Here is a great opportunity for theory, simulation, and experiment to work in synergy to guide the approach into the future. Funded by BES at a cost of $4.7 million, this beamline is an extension of the laser-driven electron-beam-slicing source currently in use on bend-magnet Beamline 5.3.1. Many of the techniques to be developed on this beamline will find direct applications in the experimental program at the LCLS.

4.3. MERLIN (Beamline 4.0.1)

Low-energy excitations are crucial to understanding the behavior of strongly correlated systems. Studying these systems requires tools with ultrahigh resolution. MERLIN is an undulator beamline with full polarization control from an EPU in the VUV energy range below 150 eV. It is designed to provide ultrahigh energy resolution for angle-resolved photoemission and inelastic x-ray scattering. It is funded by BES at a cost of $3.5 million.

4.4. Soft X-Ray Microscope XM-2 (Beamline 2.1)

A bend-magnet beamline is being constructed as a “National Center for X-Ray Tomography” for high-resolution soft x-ray microscopy and tomography of biological cells. It is funded jointly by the NIH and DOE/BER at a cost of $2.6 million for construction (plus $6.4 million for operations over five years).

4.5. Microdiffraction (Superbend)

Funds have been secured from the NSF to migrate our highly successful microdiffraction program from its bend-magnet beamline (7.3.3) to a new home on a superbend.

5. Proposed New Beamlines: Wave One

We plan to exploit the source developments described above to extend experimental capabilities with high spatial and temporal resolution and utilize the remarkable coherence properties of the ALS. Top-off operation will make possible the replacement of our 11-year-old 5-m-long undulators with pairs of chicaned 2-m-long modern insertion devices with superior performance, feeding a new generation of beamlines to address the outstanding problems of the coming decades. The initiatives outlined below are new, and proposals for funding will be prepared shortly.

5.1. Coherent Scattering and Diffraction Microscopy (Sector 12)

As our highest priority we propose to establish in half of Sector 12 a beamline to provide coherent light in the 0.5–2 keV range with full polarization control. The motivation for this initiative has several parts:

(a) The quest for nanoscale tomography: Seeing inside structures. The ability to image in three-dimensions the internal structure of complex, fine-grained materials at high spatial resolution is an outstanding challenge with an urgent need in materials science. These materials span the range from labyrinthine, mesoporous catalysts to electronic devices.

(b) Seeing inside biological structures. The grand challenge of whole-cell imaging at molecular resolution forms the basis of a substantial worldwide research effort. A tomographic single-particle imaging technique that can identify and locate large proteins or macromolecular assemblies of known crystallographic structure within a cell would make an immense contribution. The ALS effort will complement confocal electron microscopy cryostudies of smaller cells.

(c) The time domain is a new frontier. The time evolution of mesoscopic systems is crucial to understanding advanced materials and emergent phenomena—there are subtle types of order, i.e., topological order, that are not long-range in nature, but possess fascinating phase transitions nonetheless. Also, the use of soft x rays is an entirely new direction for correlation spectroscopy to study fluctuations in magnetic systems and in soft condensed-matter systems, including biological systems.

One branch of this beamline will serve the soft x-ray coherent scattering community, where much of the interest is in magnetic phenomena. This approach is designed to study time correlation as well as magnetic-field and temperature-dependent correlation and hysteresis phenomena. The other branch will be devoted to diffraction microscopy. This new form of lensless imaging is designed to provide 3D structures to 10-nm resolution for frozen hydrated biological specimens and even higher resolution where radiation damage is not a limitation. This will be a major new venture in the use of soft x rays as a nanoscale probe.

5.2. NanoARPES (Sector 12)

ARPES at the ALS and elsewhere has emerged as a leading technique for understanding the electronic structure of high-temperature superconductors and other complex oxides. Often, the most interesting materials are intrinsically, or extrinsically, inhomogeneous (i.e., in nanoscale phase segregations). Small probe sizes enable the isolation of more homogeneous, perfect materials than can be achieved by interrogating the entire sample. The quality of the science that can be extracted tends to be directly related to the sample quality. Smaller probe size translates to better science. In some other cases (as with transuranics), larger specimens would pose unacceptable hazards.

Work done by CXRO at the ALS has led to the development of truly remarkable optics for EUV lithography. As the Sematech-sponsored activity in Sector 12 winds down, we propose to capitalize and further build on its success. In collaboration with CXRO, we propose to use EUV optics to create a 100-nm probe for a nanoARPES facility using the other half of Sector 12. This will be a unique capability for the study of surfaces and structures that cannot be prepared in larger formats and for nanostructures created in the Molecular Foundry. NanoARPES will specialize in valence-shell photoemission at 92-eV energy. The other branch of this beamline will be devoted to continuing development and testing of EUV optics.

5.3. Time-Resolved SAXS in Partnership with the Molecular Foundry (Superbend)

What are the rules that govern self-organization? This question spans a broad range of topics, from correlated electron systems to protein folding, to surfactant-coated nanoparticle ripening to form monodispersed size distributions and beyond (to the organization of the cosmos). The new materials studied apply to many advanced national missions such as space exploration, the construction of particle accelerators, medical advances, and the U.S. energy problem, which has become a homeland security and environmental issue. The materials that are investigated utilizing the unique capabilities of the ALS are also used to create modern-day computers. A new superbend beamline will be constructed for time-resolved small-angle scattering. This facility will make it possible to follow, in real-time and with elemental discrimination, the synthesis and self-assembly of novel nanostructures. This will facilitate the development of joint programs with the Molecular Foundry, LBNL's Nanoscale Science Research Center (NSRC), along with several existing beamlines that will be available on a part-time basis, including Beamlines 11.3.1 (small-molecule crystallography) and 10.3.2 (micro-XAS).

6. Proposed New Beamlines: Wave Two

6.1. Enhanced VUV Spectroscopy (Sector 10)

Each of the above facilities will open new, unique capabilities at the ALS in service of the user community. They are well-matched to the capabilities of the upgraded storage ring and serve the core constituency of the ALS. In addition, the large majority of the older ALS beamlines are in need of a significant upgrade so they can continue to do cutting-edge science. Most importantly, we need to keep some of the flagship beamlines, which have been operating for a decade in an ever-more oversubscribed mode, at the cutting edge. The highest priority is to chicane the Sector 10 straight section and give each branch—the photoemission branch (HERS) and the atomic/molecular physics branch—a separate EPU for full polarization control and a separate beamline so they can run simultaneously. This beamline has been exceedingly productive in terms of high-profile publications and citations. Each of the new, separate beamlines will be application-specific, optimized for the scientific program of the two user communities, without the need for the compromises of the shared beamline in current use.

6.2. Ultrafast Magnetism (Sector 6)

How fast can you demagnetize a magnet? What are the mechanisms? Studies of fast, time-dependent magnetic effects will shed light on both basic and technologically important problems involving domain switching, vortex dynamics, and exchange interactions. In Sector 6, a half-length small-gap undulator will be installed to feed the slicing source. We plan to place an EPU in the empty half of the same straight section to be time-shared between a new, dedicated program in ultrafast magnetism and the soft x-ray branch of the slicing source. This new facility will focus a confluence of experimental and computational interest into problems that overlap synergistically with the mission of the Molecular Foundry and the community that is coalescing around ultrafast phenomena in general.

6.3. Q-Resolved Inelastic Scattering Beamline, QERLIN (Sector 2)

While the MERLIN beamline is designed for the ultimate energy resolution in the energy range below 150 eV, there is a great need to extend the capability for ultrahigh resolution inelastic x-ray scattering (IXS) investigations to energies at least as high as 1 keV, so as to be able to scan the q-vector out to the Brillouin zone boundary. The ability to map the q-dependent dispersion relations of exotic elementary excitations in complex media is key to understanding many outstanding problems in condensed-matter physics. The elemental, spin, and orbital sensitivity of resonant soft x-ray scattering offers a unique combination of capabilities that will lead to many high-impact experiments. We plan to build on the experience at MERLIN in designing this new facility, which should fit into Sector 2 with a modest rearrangement of accelerator components. This beamline will have to be extra long, and this is the only location at the ALS, where the necessary length is available. The incorporation of very high resolution photoemission in the 1-keV range would be considered.

7. Proposed New Beamlines: Wave Three

7.1. Enhanced Soft X-Ray Spectroscopy (Sectors 7 and 8)

The flagship beamlines in Sectors 7 and 8 are prolific generators of world-class research and high-profile publications. Yet each would benefit from the replacement of the old 5-m undulators with brighter EPUs and new optics. Chicaning these straight sections to add beamlines is also under consideration.

7.2. Crabbing a Bend-Magnet Beamline

If picosecond crabbing turns out to be viable, attention will turn to finding an appropriate location. One possibility would be to place the crab and decrab cavities in one half of straight sections 7 and 8, thereby delivering picosecond pulses from the 7.3 bend-magnet ports. The picosecond nanomagnetism studies already underway on the PEEM-2 microscope on Beamline 7.3.1 would benefit greatly from the shorter pulses. Following the planned migration of the microdiffraction program to a superbend, the 7.3.3 port would become available for an ultrafast program.

8. Infrastructure and User Support

To maintain and further improve the position of the ALS as the premier user facility for soft x-ray and VUV science, the source and beamline developments described above are necessary, but not sufficient. The ALS needs to create an even safer, even more user-friendly and supportive environment.

8.1. Safety First

The safe operation of the facility and the user program is the top priority of both ALS management and the ALS community. As the user community grows and the experimental floor becomes more crowded, maintaining and further improving our excellent safety record becomes an ever-increasing challenge. We will continue and enhance the safety training of staff and users alike and will redeploy staff to increase the coverage of beamline coordinators to provide more safety support to users.

8.2. Beamline Staffing

The staffing level of most of the beamlines is barely half of what is considered optimal. Our remarkably talented and dedicated staff is stretched thin and are heavily overloaded. It is a general observation that staffing levels go hand-in-hand with scientific productivity, and hence the facility is significantly underutilized. The intellectual excitement of the ALS as a forefront science facility has been a powerful tool in the recruitment and retention of outstanding staff, but additional sustained efforts are required to increase diversity both in gender and in underrepresented groups. We will seek support to increase beamline staff so as to optimize utilization of the facility.

8.3. User Support Building

Both safety and productivity are jeopardized when crowding becomes extreme, when there is inadequate lab and office space available to support the program. LBNL has proposed and designed a User Support Building to relieve this serious situation. This is a very high priority for the ALS, and the request for funding is pending with the DOE.

8.4. User Hostel

As with any user facility that operates around the clock, providing adequate housing and meal service to users is essential. The current arrangement (provision of leased ALS apartments) does not satisfy the need, as there is not enough capacity, and the location is quite noisy. LBNL has proposed a plan to construct a User Hostel within walking distance of the ALS and the LBNL cafeteria. The building would be built and run by private contractors, with the cost recovered from rental fees.

8.5. Education and Visitor Program

To build a more diverse scientific staff, the ALS has to contribute to the “pipeline” of qualified applicants. The ALS Doctoral Fellowship Program, initiated about four years ago, has been very successful in attracting graduate students for carrying out doctoral research in synchrotron radiation science and providing them with a high level of technical training. We intend to expand this program with special emphasis on underrepresented groups. ALS also envisions starting a distinguished postdoctoral fellowship program with the same emphasis, to increase and diversify our pool of candidates for beamline scientist positions.

The Doctoral Fellowship Program also provides a novel and cost-effective way to train the next generation of theorists to work with facility scientists, as well as to engage thesis advisors free of charge. It will also assure a healthy turnover in the talent pool.

The ALS will continue to provide a stimulating environment for visiting scientists. Attracting students to work part- or full-time during the summer will continue to be a high priority. These students actively participate in ongoing projects with beamline scientists and thus get hands-on experience and training. In return they provide valuable assistance to our beamline scientists.

9. CIRCE, a Dedicated THz Source

In the longer term, we are eager to construct the terahertz source, CIRCE. A year ago, a national workshop was held on terahertz science and its future. The recently published report on this workshop concludes that, while the community needs to grow and mature, the scientific case for a terahertz user facility will become stronger. The leading candidate for a highly stable source based on coherent synchrotron radiation is CIRCE. This source is designed to make use of the ALS injection system, would sit on top of the booster ring, and would serve eight beamlines at a total price tag of approximately $20 million. This facility will provide ultrashort pulses and be well suited to a wide variety of pump–probe experiments. In the immediate future, the ALS intends to be a vigorous participant in the national THz network that was proposed in the workshop report.

Appendix: Workshops on Strategic Planning

Spring 2004 Retreats with ALS Staff

1. Electronic Structure and Magnetism — February 17, 2004
2. Materials and Earth Sciences — March 29, 2004
3. Gas Phase, Dynamics and Nanoimaging — April 5, 2004

ALS-UEC Retreat — June 9–10, 2004

ALS Photoemission Crosscutting Workshop — July 29–30, 2004

Users' Meeting Workshops — October 2004

1. Actinide Spectroscopy at the ALS
2. Advances in Crystallographic Data Analysis and Acquisition
3. Magnetic Nanostructures, Interfaces, and New Materials: Theory, Experiment, and Application
4. Nanoscience at Synchrotrons
5. New Complex Materials for Synchrotron Science
6. New Directions in Hard X-Ray Microspectroscopy and Spectromicroscopy
7. Photon-In and Photon-Out X-Ray Spectroscopy in Material Sciences, Environmental Energy, and Chemical Analysis
8. X-Ray Microscopy: Advances and Challenges
9. What's Behind the Shielding? An ALS Accelerator Tutorial
10. Modern Valence Band Photoemission Spectroscopy: The Legacy of W.E. Spicer and a Powerful Tool for Materials (Joint ALS–SSRL workshop at SSRL)